Operator Workload Evaluation of Reactor Start-up Operation in the Nuclear Power Plant

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1. Introduction

Operation automation, one of the powerful methods to prevent human error in the nuclear power plant, is becoming visible due to the development of artificial intelligence (AI) technology and Big-data analytics. Improved reliability of AI and Big-data is the driving power to force human operator to stand at the out-of-loop.

Normal operations in the nuclear power plant are usually highly-automated already. The start-up operation takes a long time, requires frequent communication and comprehensive decision-makings so many unexpected reactor trips caused by human operator has been occurred.

As radical automation, automation of every operator task, is infeasible now and partial automation such as automation of some parts of operator tasks is being tried in many research organization, universities and industries.

In order to select tasks to be automated, it is critical to figure out the level of operator workload for the startup operational tasks. In this study, operator workload for each task of the start-up procedure was evaluated.

2. Methods and Results

In this section procedure structure, workload evaluation and evaluation results are described.

2.1 Structure of the start-up procedure

The operation range from the cold shutdown to a power level 5% state was chosen for evaluating operator workload because it covers most of complex operational situation of the start-up operation.

The start-up operational procedure is divided by operational modes. Two operational procedures that covers from cold shutdown to hot standby (Procedure#3001) and hot standby to power operation (Procedure#3002) are included in the operator workload evaluation.

The start-up operational procedure has many chapters as followings:

I. Purpose
II. References
III. Cautions and Limitation
IV. Procedure
V. Annex

Chapter IV describes operator tasks that automation system can take up their objectives instead of human operators. Chapter IV is structured hierarchically as following:

- Section: highest level; labeled in number
- Sub-section: middle level; labeled in Korean
- Sub-sub-section: lowest level; labeled in number with a bracket

A sub-section can include sub-sub-sections and a section can have no sub-section.

2.2 Workload Evaluation

It is so difficult to evaluate an accurate workload level of a task because many factors and situation affect operator workload. Objective measurements such as bio-signal based physiological methods can be used to get a quantitative workload level in real time. It required, however, dedicated equipment and a postulated operational situation are necessary. In contrast, subjective measurements such as questionnaires and interviews are easily applied to investigate workload level without equipment nor simulation, However subjective matter experts or experienced subjects are essential to measure workload.

In this study, five (5) experienced and licensed operators were participated. Their average operating experience is over 30 years.

They were asked to evaluate workload for each procedure section, sub-section and sub-sub-section of the start-up procedure, Procedure#3001 and Procedure#3002.

A workload level for a sub-sub-section can be scored from 1 (the lowest workload level) to 9 (highest workload level). The workload level of sub-section is a mean value of its sub-sub-section scores and the workload level of a section is an average of its sub-section's workload levels.

2.3 Workload Evaluation Scores

Fig. 1 and Fig. 2 shows SMEs evaluation scores along with procedure sections of Procedure#3001 and Procedure#3002. Most of scores are ranged from 3 to 8.

Mean and standard deviation of each SME are tabulated at Table. I and Table II.

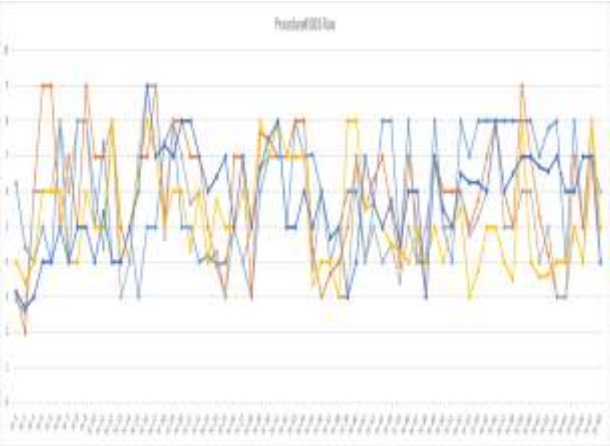

Fig. 1 Evaluation scores from five experienced operators for Procedure#3001 (from cold shutdown to hot standby)

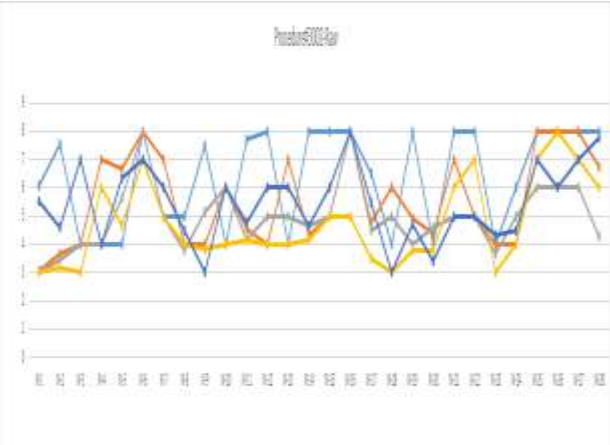

Fig. 2 Fig. 2. Evaluation scores from five experienced operators for Procedure#3002 (from hot standby to 5% power operation)

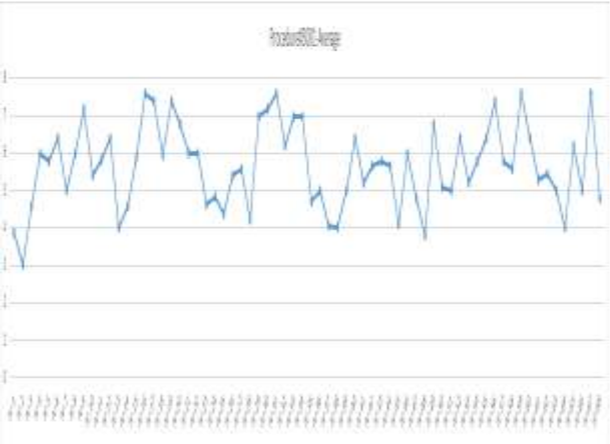

Fig. 3 Average score of experienced operator's evaluation for Procedure#3001 (from cold shutdown to hot standby)

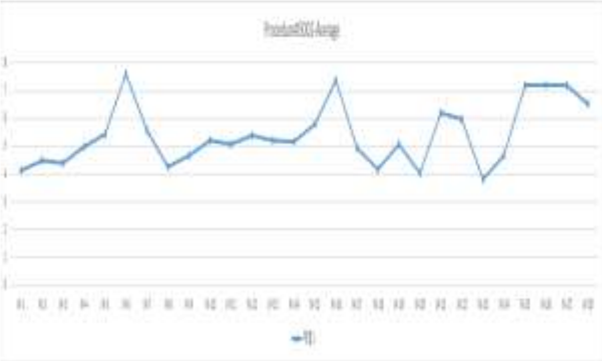

Fig. 4 Average score of experienced operator's evaluation for Procedure#3001 (from cold shutdown to hot standby)

Table I: Statistics of Evaluation Scores for Procedure#3001

	mean	Standard deviation
SME 1	5.961967720	1.711134053
SME 2	5.968369615	1.801023611
SME 3	5.440382842	1.622739450
SME4	5.227060574	1.436063331
SME5	5.735083843	1.410175922

Table II: Statistics of Evaluation Scores for Procedure#3002

	mean	Standard deviation
SME 1	6.406261992	1.777866540
SME 2	5.611760858	1.620778428
SME 3	4.718688587	1.466425977
SME4	4.961215042	1.168977573
SME5	5.448435229	1.336009883

The average score difference among SMEs is 2.963511231 for Procedure#3001 and the biggest score difference among SMEs is 5 point at section 3 (Initial condition verification), 4 (SIT level control), 39(VCT high-level interlock set-point verification), 63 (Verification of RCS non-load temperature) of Procedure#3001.

The average score difference among SMEs for Procedure#3002 is 2.810787691 and the biggest score difference among SMEs is 4.5 point at section 9 (Verification of set-point of reactor test).

2.3 High level of Workload

From the evaluation scores, operators are expected to take the highest level (7.6) of workload for several tasks as followings:

- Procedure#3001 Section 16 (Checking before RCP startup)

- Procedure#3001 Section 31 (Maintaining PZR level at 40%)
- Procedure#3001 Section 59 (Leakage test of RCS pressure isolation valve)
- Procedure#3001 Section 67 (Pre-heating turbine)
- Procedure#3002 Section 6 (Pre-heating turbine)

3. Conclusions

Investigation of workload level for each procedure task is essential to make a plan for automation of start-up operation. Evaluation process by experienced operators was carried out for start-up operation from cold shutdown to 5% power operation. As the results, tasks that give operators high level of workload were identified.

It is beneficial to automate the high level workload tasks for human error reduction and safety. This study provide essential information for planning task automation strategy.

Acknowledgements

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